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STEATITE CERAMIC BASED ON TALC FROM THE UPPER AMUR REGION

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A structural and chemical analysis of talc from the deposit in the Zeya region (Lozhnikovskoe showing) in the Amur region was performed. Experimental samples of a steatite ceramic were obtained. The electrophysical and mechanical characteristics of the material obtained were investigated.

Key words: talc, magnesium metasilicate, steatite ceramic, mineral raw material.

The talc deposit in the Zeya region (Lozhnikovskoe showing) on the left bank of the Gar' River could become a base for development of steatite ceramic production in the Amur region. Based on prognostic estimations alone, the resources of this deposit will reach approximately 100 million tons. The quality of the talc raw material was first studied in the chemical laboratory Dal'geologiya Amur Region Geographic Society [1]. With respect to the content of the leading component, talc, constituting 77.3%[3] on average (with ordinary contents of 70 – 80%), this is high-quality raw material. Talc is aqueous magnesium silicate, which has a laminar structure similar to the structure of clay minerals. The ideal formula of talc is $Mg_3(Si_2O_5)_2(OH)_2$. Talc is a secondary mineral formed from silicate rocks rich in magnesium. Similar to clay minerals, talc is characterized by softness, perceptible greasiness, and is easily cleaved along cleavage planes [2]. The composition of the talc mineral itself is usually homogeneous, but in natural raw material some minerals accompany it as a function of the type of bed rock. Iron and alkali compounds are the most undesirable. At the firing temperature, talc serves as a source of magnesium-silicate melt.

In external appearance, talc from the Garinskoe deposit consists of relatively large grey chunks with white mottling. After crushing talc-containing rock to 100 μm and more, it was found that two fractions that differ in color and size can be distinctly separated: a small yellow-brown fraction and a larger grey fraction. X-ray phase analysis (XPA) did not show any significant differences in the chemical composition of these fractions (Table 1). However, x-ray structural analysis revealed some of their features (Table 2).

Guided by the composition of the initial talc and assuming that all of the magnesium oxide reacts, forming magnesium metasilicate, the composition of the ceramic paste was calculated [3]. The approximate calculation showed that 18.0% kaolin, 4.8% quartz-feldspar raw material from the Chalganskoe deposit [4], and 1.6% magnesium should be used for 74.9% talc. We should stipulate that this calculation is not totally correct due to the hypotheses advanced, but can be used to determine the approximate stock steatite mass.

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[3] Here and below — content by weight.

TABLE 1. Results of X-Ray Fluorescence Analysis of Talc Fractions

Fraction	Mass content, %											
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	other	total
Grey	58.47	0.11	1.52	5.76	0.13	28.51	0.34	0.21	< 0.02	< 0.02	5.02	100.08
Yellow-brown	59.21	0.10	1.42	5.52	0.15	27/98	0.36	0.18	< 0.02	< 0.02	5.23	100.15
	Content of elements, 10^{-6}											
Fraction	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba
Grey	23	1543	67	1522	14	50	6	< 10	< 3	< 3	< 3	29
Yellow-brown	21	1253	73	1577	13	36	6	< 10	< 3	< 3	< 3	33

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TABLE 2. Results of X-Ray Structural Analysis of Talc Fractions

Fraction	PDF 2008 file number	Chemical formula	Name	Syngony	d1	d2	d3
Yellow-brown	00-003-0887	$Mg_3(Si_4O_{10})(OH)_2$	Talc	Monoclinic	2.4800	1.5300	4.5500
Grey	00-002-0570	$3MgO_4(SiO_2)(H_2O)$	Talc Soapstone, Steatite	Monoclinic	3.1100	9.3000	1.5200

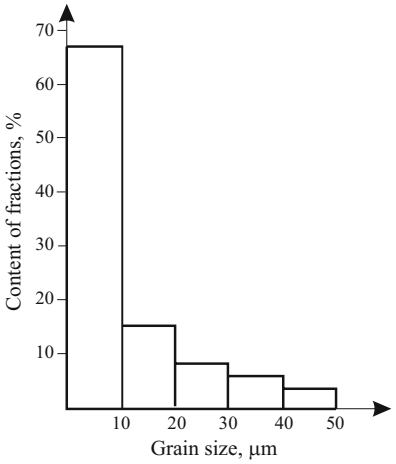

Fig. 1. Particle size distribution in initial mixture.

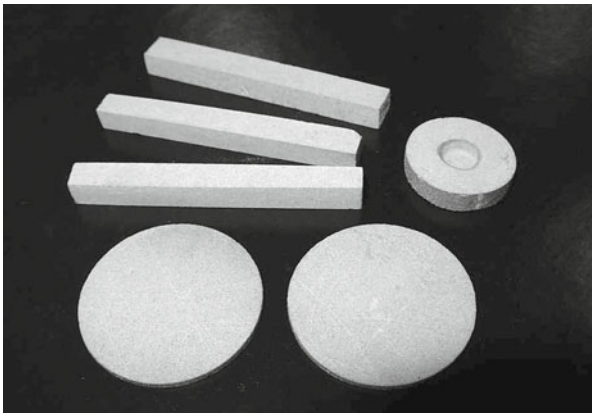

Fig. 2. Ceramic samples for mechanical and electrophysical tests.

The initial raw material was first crushed separately, organic contaminants were removed, and then it was processed in a magnetic separator. The necessary composition was obtained by combined dry grinding in a ball mill to the given batch particle size. The granulometric composition was controlled by an optical method. The characteristic particle size distribution of the initial mixture is shown in Fig. 1.

Distilled water was poured in the prepared batch and left to break up for 18 h. Excess moisture was removed by drying under an infrared lamp. The powder mass moistened to the state of the best plasticity was molded in molds under pressure. The size and shape of the ceramic samples resulted from the requirements of GOST 24409–80 for conducting electrophysical and mechanical studies. The tests of the compositions showed that at a low content of clay materials, molding of the samples is impossible without using binders (paraffin, polyvinyl alcohol).

The first (unglazed) firing of the samples was conducted in a muffle furnace using an alumina charge. The firing time was 10 – 12 h. The average temperature elevation rate was 1 – 2 K/min. The samples were held for 1 h at the firing temperature of 850°C and cooled in the furnace after it was switched off. After firing, the samples were mechanically processed to obtain the assigned dimensions. The final firing of samples of the given shape (Fig. 2) was conducted at temperatures of 1250, 1280, and 1310°C.

An x-ray diffractometer (ÉFA MD-10 minidiffractometer using CuK_α radiation with a Ni filter in the 2θ range from 16 to 70°) was used to study the phase composition of the ceramic obtained. The PDF2008 database was used to interpret the diffraction patterns. The analysis of the microstructure and elemental composition of the samples was conducted with a scanning electron microscope with a JEOL JSM 6390LV energy-scattering spectrometer. The density of the samples was measured as a function of the sintering temperature by the Archimedes liquid method using distilled water. The dielectric characteristics were determined with the bridge method at frequencies of 100, 10^3, and 10^6 Hz at room temperature. A copper coating obtained by vacuum magnetron sputtering was used as electrodes. The bending strength was studied with a three-point loading scheme on an IR-5046-5 tensile-testing machine.

A feature of sintering of steatite pastes is that the material has a narrow sintering range. This is due to the rapid rise of the melt in the narrow temperature region of 20 to 40°C. Due to this situation, selection of the sintering temperature is important for obtaining material with high performance properties.

The characteristic microstructure of fracture of a ceramic sample obtained at a different firing temperature is shown in Fig. 3.

As Fig. 3 shows, firing of the ceramic sample at low temperatures causes formation of a loose structure (Fig. 3*a*) and high porosity of the material (Fig. 3*b*). Increasing the sintering temperature causes intensive formation of glass phase followed by deformation of the sample.

Production of steatite ceramic is based on formation of a crystalline phase in the form of magnesium metasilicate ($MgSiO_3$) and a glass phase of complex composition that ensures sintering of the steatite material. Magnesium meta-

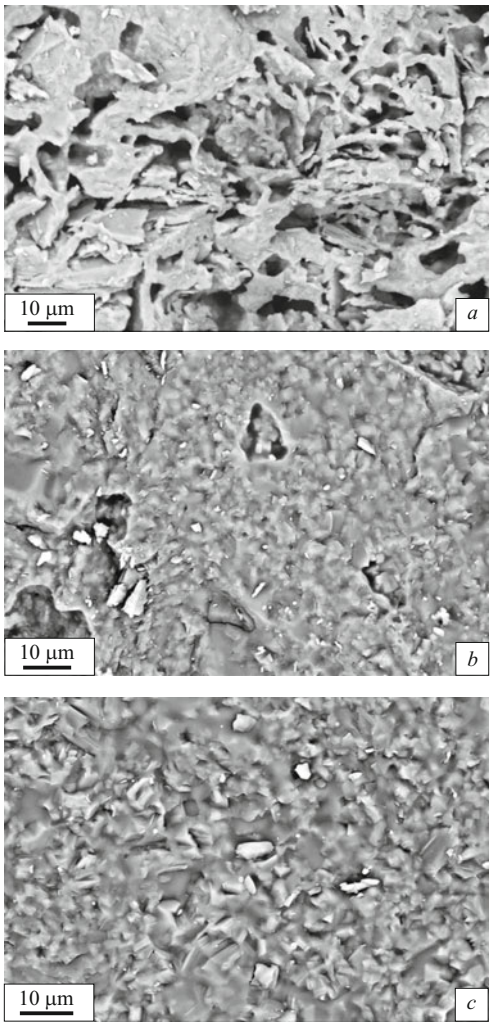

Fig. 3. Microstructure of the fracture surface of ceramic samples fired at different temperatures: *a*) 1250°C, 1.5 h; *b*) 1280°C, 1.5 h; *c*) 1310°C, 1.5 h.

silicate, $MgSiO_3$, usually exists in the form of a high-temperature phase that tends toward aging and conversion into clinoenstatite, which is accompanied by perturbation of the continuity of the material. The stability of the structure obtained is ensured by a high content of a glassy phase and a small crystalline phase particle size [5, 6]. The results of the x-ray phase analysis of the samples obtained at sintering

TABLE 3. Mechanical Properties of Steatite Ceramic

Sample	Firing temperature, °C	σ_b, MPa	ρ, g/cm^3	Water absorption α, %	Linear shrinkage, %
Experimental	1250	80.1	2.13	14.50	5.54
	1280	80.4	2.21	2.40	8.92
	1310	101.6	2.31	0.36	13.68
SPK-2		120.0	2.66	–	–

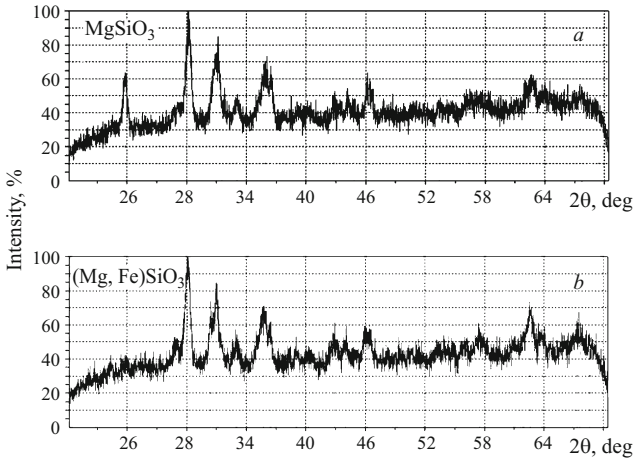

Fig. 4. Diffraction pattern of a sample of steatite ceramic fired at a temperature of: *a*) 1250°C; *b*) 1310°C.

temperatures of 1250 and 1310°C are shown in Fig. 4. The analysis of the data revealed the structure of the ceramic material in the form of protoenstatite and a solid solution of $(Mg, Fe)SiO_3$. The approximate content of glass phase was 32%.

According to GOST 20419–83, steatite ceramics belong to group 200.

Basic Requirements for Steatite Ceramic

Density, g/cm^3 . . . . . 2.8
Apparent porosity, %, max 0.7
Staining in fuchsin . . . . . Absent
Strength, MPa, not less than:
  bending 120
  tensile 45
  compressive . . . . . 500 – 600
Electric strength at frequency of 50 Hz, kV/mm . . . . ≥ 20
Relative dielectric constant at frequency of 50 Hz . . . . . From 5 to 7
Dielectric loss tangent at 50 Hz . . . . . $< 5 \times 10^{-3}$
Volume resistivity at room temperature, Ω · m . . . . $\geq 10^{11}$

We note that these parameters were established for the samples with the method indicated in the GOST; these indexes can differ for samples of other sizes and fabricated with other technologies. This especially concerns the electric strength, whose value is a function of the duration of exposure to stress, the sample thickness, frequency, temperature, degree of electric field homogeneity, and microstructure of the ceramic [6, 7]. The mechanical and electrophysical characteristics[4] of the material obtained are reported in Tables 3 and 4. The data for the standard ceramic SPK-2 are shown for comparison.

[4] The electron-microscopic and x-ray phase analyses were conducted at the Center for Mineralogical and Geochemical Studies at the IGRM, FEB RAS; the analysis were V. I. Rozhdestvina, Ya. N. Kisel', and T. B. Makeeva.

TABLE 4. Electrophysical Properties of the Steatite Ceramic Obtained

Sample	Firing temperature, °C	Dielectric constant ε, F/m			Dielectric losses, tan δ			Volume resistivity ρ, Ω · m	Electric strength E_{st}, kV/mm
		100 Hz	1000 Hz	1 MHz	100 Hz	1000 Hz	1 MHz		
Experimental	1250	8.86	5.80	4.93	0.25	0.030	0.006	10^9	10
	1280	8.30	7.70	5.30	0.10	0.010	0.007	$3 \cdot 10^{11}$	14
	1310	7.20	9.05	6.90	0.01	0.007	0.006	$3 \cdot 10^{11}$	20
SPK-2 [8]		7.20			0.0037	0.0033	0.0023	$5 \cdot 10^{11}$	40

The insignificant worsening of the properties of the ceramic is probably due to the high Fe_2O_3 content and the necessity of a more detailed study of all stages of the manufacturing process.

The above suggests that natural talc from the Upper Amur Region could be totally suitable raw material for production of steatite ceramic and other materials based on it.

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